Aging Aircraft 2005

The 8th Joint NASA/FAA/DOD Conference on Aging Aircraft

Decision Algorithms for Electrical Wiring Interconnect Systems (EWIS) Fault Detection

Dr. Eric Bechhoefer: Goodrich Aerospace
Ryan Hanks: NAVAIR 4.4.4.3

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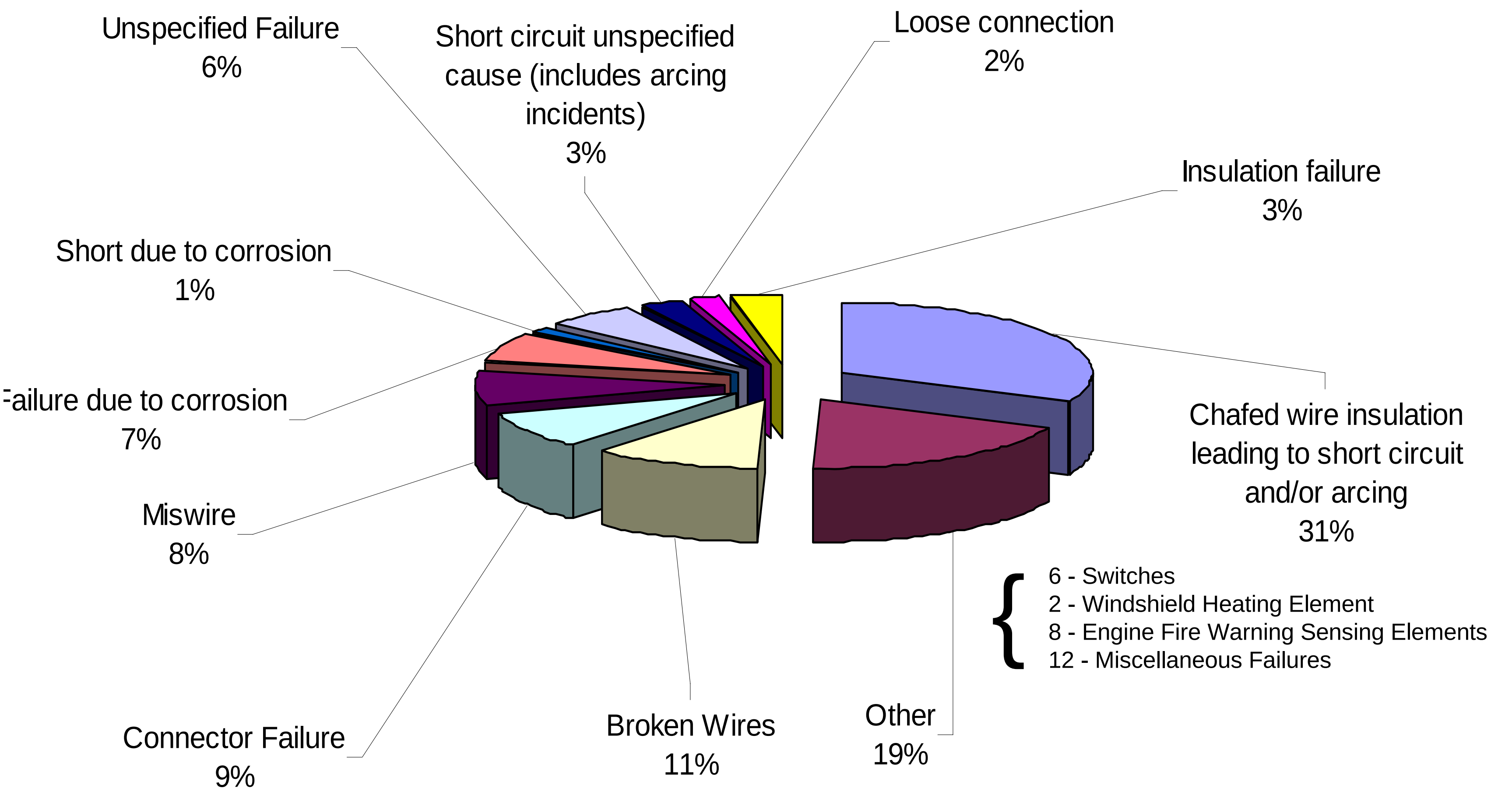
Aging Fleet of Aircraft

- **Aging Fleet of Aircraft**
  - Wire Becoming an Increasing Problem resulting in:
    - Malfunctioning Avionics Equipment
    - Electrical Fires
    - Mission Aborts
  - Few Tools Available to the Maintainer for Troubleshooting
- **If Failure: Replace LRU**
  - Wire Only Considered After the Fact
- **Better Tools May Allow Development of Periodic Wire Maintenance Procedure**
  - On Condition Maintenance?
- **Development of Hand Held TDR**
  - Signal Processing and Decision Algorithms to Facilitate Wire Diagnostic

Aging Aircraft 2005

Failure Modes For Aircraft 1997-2001



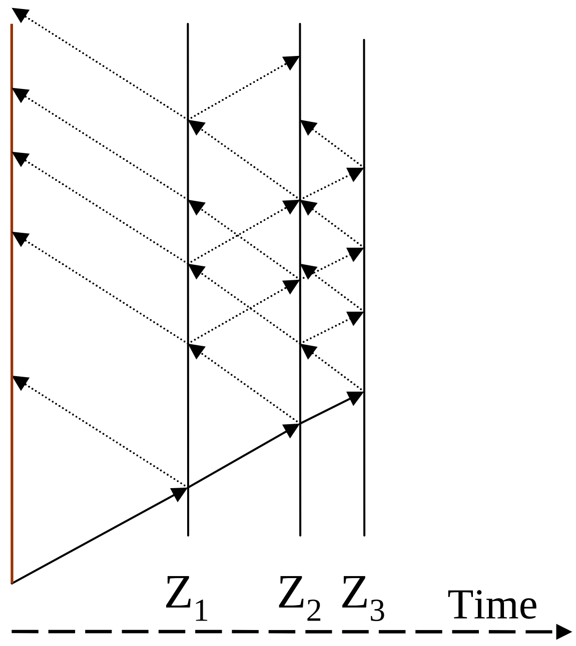
(Source: Navy Safety Center Hazardous Incident Data)

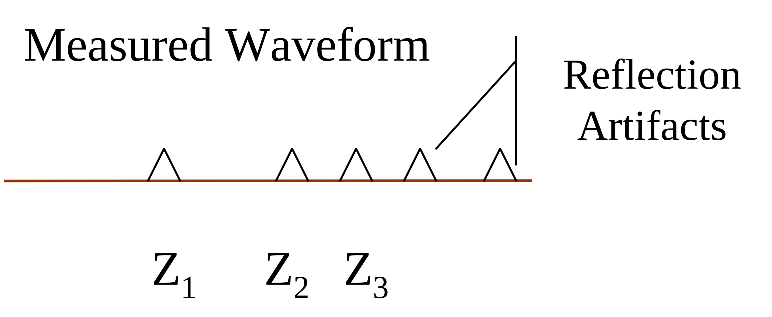
Hardware Considerations

- **Time Domain Reflectometry**
  - Fast Risetime: High Bandwidth
    - Should Allow Detection of Smaller Changes in Wire Characteristic Impedance
    - Characteristic Impedance Could be used for Identification of Different EWIS Events
- **PCMCIA Format TDR Card**
  - 148 Ps Risetime
  - Sequential Sampling Allows for 5 GSPS (200 ps sample rate)
  - ADC Analog Bandwidth of 1 GHz
- **Initial Results of GWIT are Promising**
  - Opens, Shorts
  - Soft Faults: Chafe/Splice, Connectors on Coax, Twisted Shielded Pair, Triple Twisted Shielded

Analysis Issues: Inverse Scattering

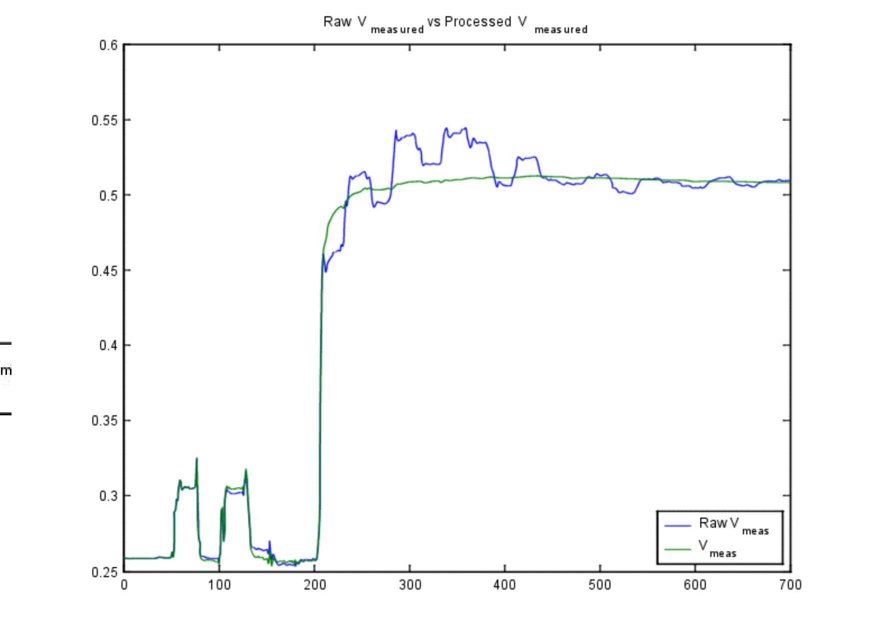
- **A Change In Characteristic Impedance Causes a Change in the Reflected Voltage**
  - $V_{Refected} = [(Z_2 - Z_1)\ V_{Incident}]/(Z_2 + Z_1)$
- **Complicates Matters When There Is More Than One Change in Impedance**
  - Interferes With Fault Detection and Classification
  - Would Like To Remove Effects

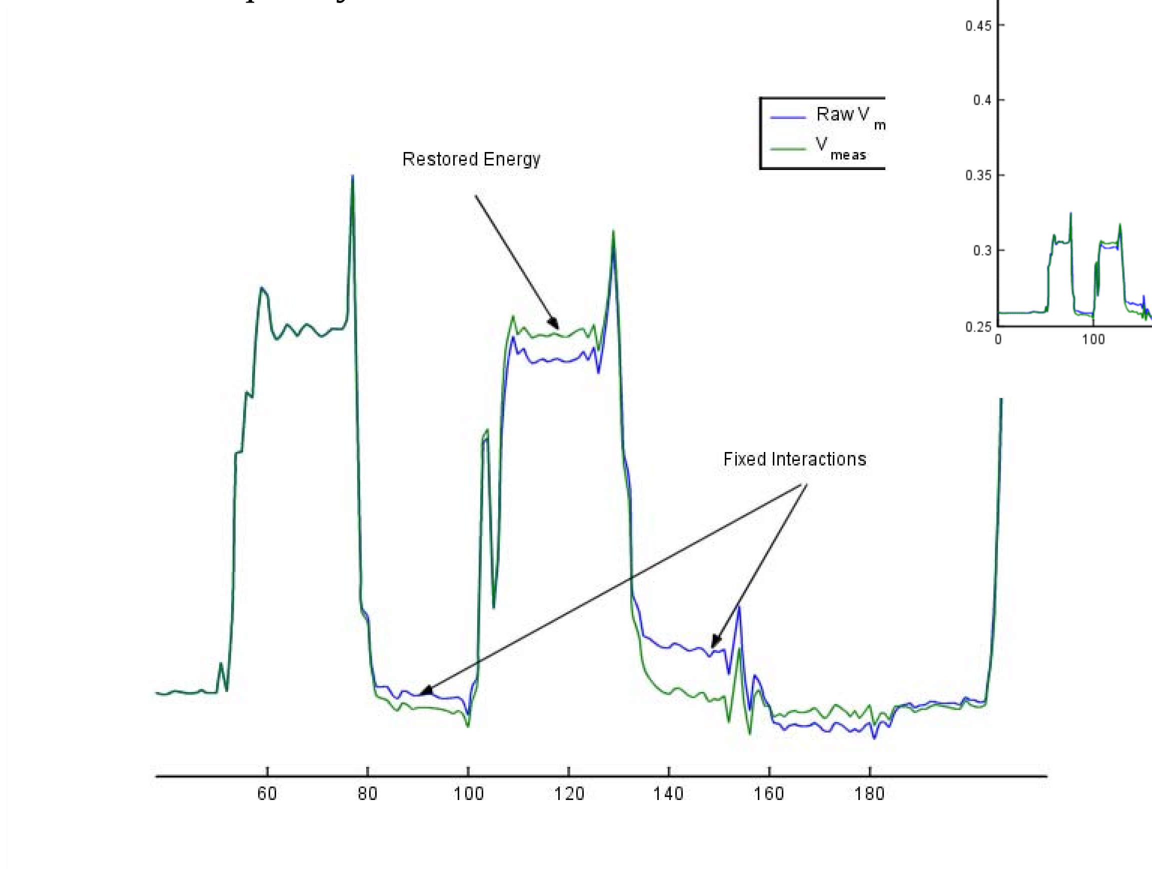




Scattering Effect Adversely Distorts Measurement

- **Simplifying Assumptions:**
  - Goupillaud medium
  - Step Function
  - No Frequency Attenuation





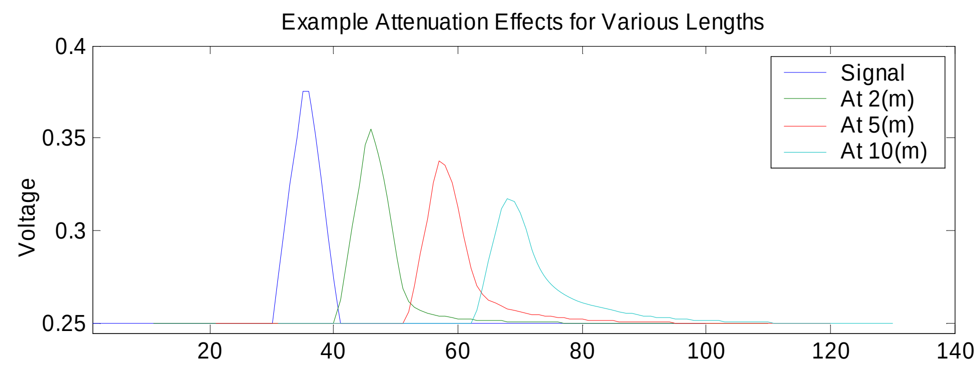
Frequency Attenuation

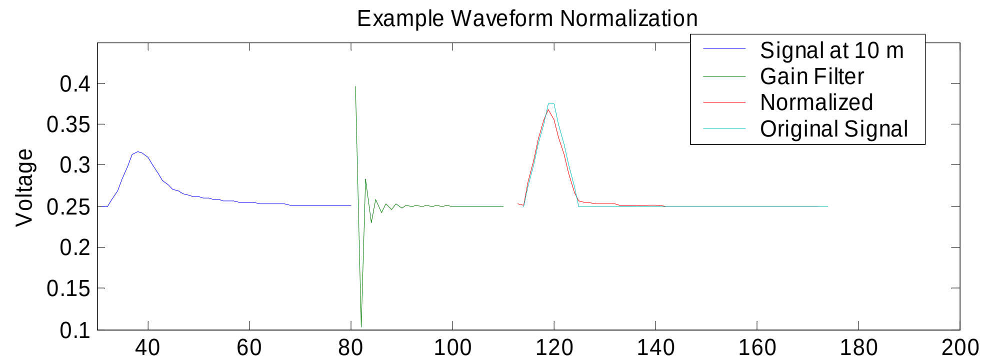
- **Step Function Gets "Stretched" in Time**
  - Attenuation of High Frequency Components
  - Caused By:
    - Skin Effect
    - Capacitance
    - Resistance
  - For Longer Transmission Lines
    - Attenuation Predominately a Function of Resistance and Capacitance
  - Modeled Attenuation as RC Circuit
    - Resistance of Wire Segment, *R = dLength2/(2r2K),*
    - Capacitance as Function of Z: *C= 1./(c*vop*z),*

Length Varying Inverse Filter

- **Calculate Transfer Function For Each Wire Segment**
  - $H_i = F(1/RC * e^{-t/RC})$
  - $b_i = F^{-1}(1/H_i)$ are the Filter Coefficients of a Convolution Matrix

$$\frac{dZ_{norm}}{dt} = \begin{bmatrix} b_1 & 0 & & 0 \\ 0 & b_2 & & \\ & & & \\ & & b_{n-1} & \\ 0 & & 0 & b_n \end{bmatrix} \bullet \frac{dZ_{Meas}}{dt}$$





Statistical Event Detection

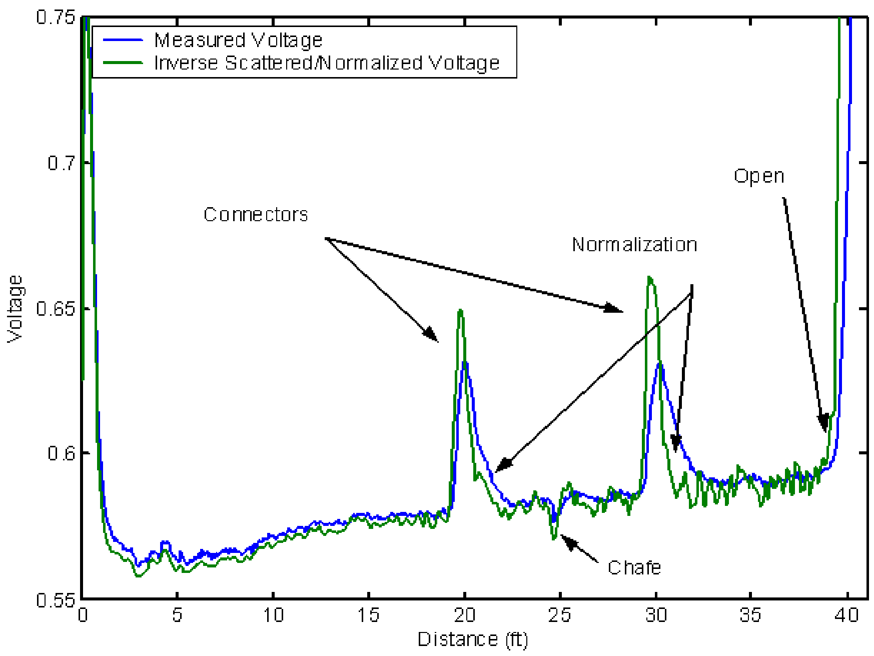
- **With Good Representation of the Characteristic Impedance**
  - Decision Algorithm for Detection and Classification.
  - Detection: Identifying Some Anomalous Event on the EWIS
  - Classification Concerned with Naming an Event to a Specific Type.
- **A Number of Decision Methodologies**
  - Artificial Neural Networks,
  - Fuzzy Logic,
  - Baysian Belief Networks
- **We Selected a Purely Statistical Approach: Hypothesis Testing**
  - A Formal Procedure:
    - Observe the Impedance
    - Formulates a Theory
    - Tests this Theory against the Observation

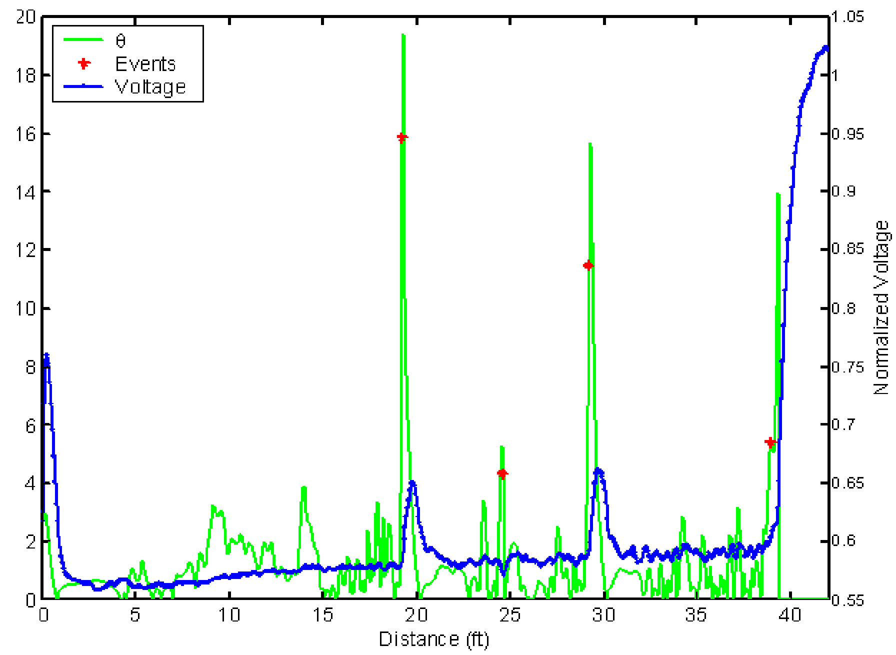
Hypothesis Test

- **The Model: Impedance is a Function of inductance and Capacitance:**
  - An Event of the Wire, Due to Chafe, ETC, Changes the Local EWIS Inductance or Capacitance.
  - This Changes the Local Impedance:
  - Formally, the test is:
    - H_0: $Z = Z_i$
    - H_a: $Z \sim= Z_i$
  - The Test Statistic is Then $\theta = \left. \hat{Z} - Z_0 \middle/ \sigma_{\hat{Z}} \right.$

- **Mean and Variance was Estimated from Prior 31 Z_i Values**
- **Type I Error was Set at 10^{-5}**
  - Say Event When No Event – i.e. False Alarm

Detection Example





Twisted Shielded Pair:

Connector->20 ft->Connector->10ft->Connector->10ft->Connector->Open

Event Classification

- **Once an Event is Detected:**
  - Multiple Hypothesis Test to Determine the Most Likely Event Type
  - The decision rule will be to choose H0 if:
    - P(H0|θ) > P(H1|θ), P(H2|θ),… P(Hm|θ).
  - For the Binary Case, the Rule becomes:

$$\frac{P(H_1 \mid \theta)}{P(H_0 \mid \theta)} \underset{H_0}{\overset{H_1}{\gtrless}} 1$$

  - Using Bayes' Rules, the Criterion is:

$$P(H_i \mid \boldsymbol{\theta}) = \frac{p(\boldsymbol{\theta} \mid H_i)P(H_i)}{p(\boldsymbol{\theta})}, \quad i = 0,1$$

  - Rearranging and Taking the Log:

$$\mathbf{ln}\, l(\boldsymbol{\theta}) \underset{H_0}{\overset{H_1}{\gtrless}} \mathbf{ln} \frac{P(H_0)}{P(H_1)}$$

Assuming Normal Distribution…

- **Gaussian Case Decision Rule**
  - Decision Space: Parametric Observation **θ** = (Zi, Zi+1… Zi+m)
  - Calculate the Square of the Normalized Distance of the Decision Space

$$\mathrm{d}^2 = (\theta - \mathrm{m})^{\mathrm{T}} \Sigma^{-1} (\theta - \mathrm{m})$$

  - The Log Likelihood Ratio Test is then:

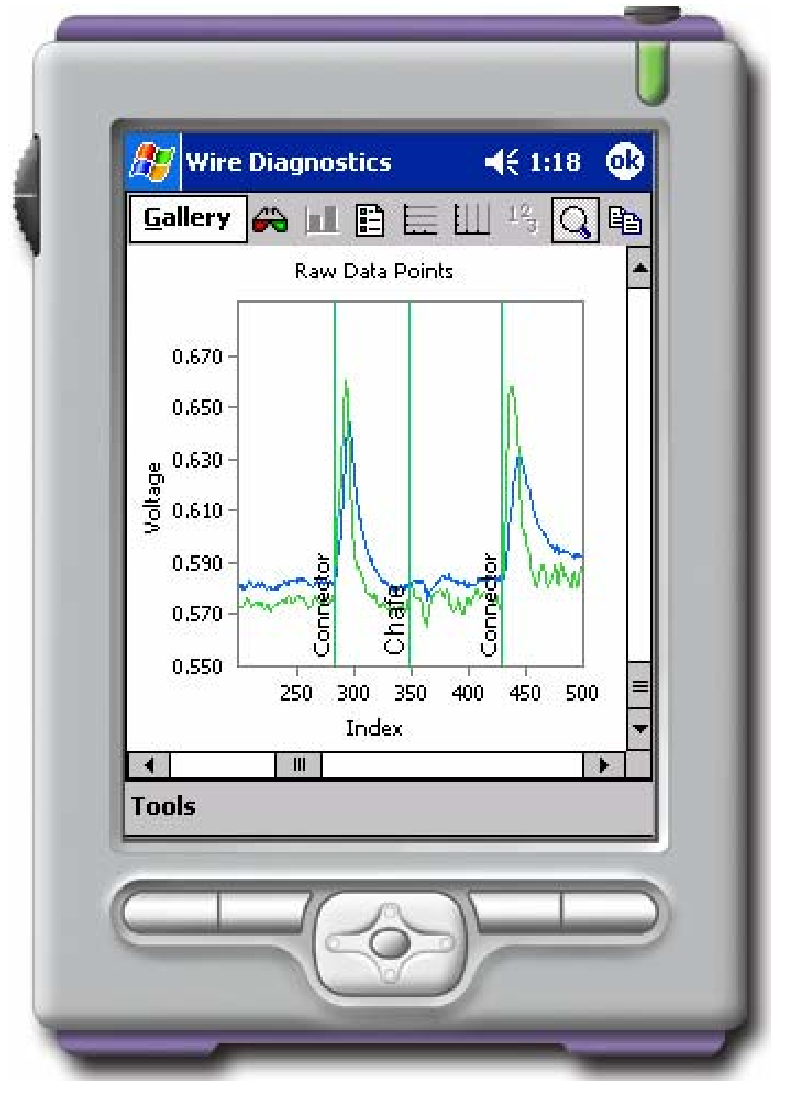
$$\tfrac{1}{2}\left[d_0^2 - d_1^2\right] + \tfrac{1}{2}\ln\left(\frac{|\Sigma_0|}{|\Sigma_1|}\right) \underset{H_0}{\overset{H_1}{\gtrless}} \ln\frac{P_0}{P_1}$$

  - Assumed Equally Likely Events (P_j are Equal)
  - For Test, Plug in the Event Mean Values and Covariance
    - For Three or More Events: Pick the Biggest, Else Accept Null Hypothesis

Example: Twisted Shielded Pair

- **Configuration Data**
  - By Wire Type:
    - TTS, TSP, TP, Single, Coax
  - VOP, Mean and Covariance of Various Events
    - Calculated From Test Harness
    - Connector, Chafe, Splice
  - Single Wire is Tough
    - Event Detection – Can't Say Much About Classification
- **Hypothesis Test Results:**

Event Type	Event @ 19.2 ft	Event @ 24.6 ft	Event @ 29.2 ft
Φ_1 (Connector)	**6196**	-4665	**7223**
Φ_2 (Chafe)	1394	**208**	2277



Discussion

- **Promising Results**
  - Detection of Chafes/Splices and Connectors on Many Wire Types
  - Single Wire: Opens, Short and “Events”
- **Good Framework for Additional Studies**
  - Improve Performance By:
    - Model Connectors
    - Take Into Account Frequency Attenuation in Inverse Scattering
    - Other Decision Algorithms
      - Detection Strategies
      - Look At Relationship Between Wires in Harness